AN EXPERIMENTAL STUDY OF ABRASIVE CUT-OFF PROCESS

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DEDICATED

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MY BELOVED PARENTS

CERTIFICATE

This is to certify that the work entitled " AN EXPERIMENTAL STUDY OF ABRASIVE CUT-OFF OPERATION" by Govind. Ramarao. Belgal has been carried out under my supervision and has not been submitted elsewhere for a degree.

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GOVIND R. BELGAL

LIST OF FIGURES

NOMENCLATURE

b	=	Width of wheel
c	=	Number of active cutting points per unit area
D	=	Diameter of wheel
d	=	Downfeed rate
d_o	=	Depth of cut in surface grinding
F_P	=	Tangential force
F_Q	=	Normal force
G	=	Grinding ratio
g	=	Nominal grain diameter
H	=	Heat transfer coefficient
h	=	Depth of cut in abrasive cut-off
h_g	=	Reduction in wheel radius
J	=	Mechanical equivalent of heat
L	=	Length of viewing
l	=	Length of cut
M_R^*	=	Material removal rate
n	=	Total number of active grains
r	=	Ratio of mean scratch width to mean scratch depth
T_a	=	Atmospheric temperature
T_s	=	Interface temperature
t	=	Undeformed chip thickness

t_o = Dimensionless time

U = Specific energy

U_s = Specific power

V = Wheel speed

V_w = Volume of wheel wear

v = Table speed in surface grinding

$_c$ = Volume of specific heat of work

β and γ = Dimensionless parameters.

ABSTRACT

In the present work, an dexperimental study has been carried out to identify the important variables in the abrasive cut-off operation, a stock removal process. The performance of cut-off wheel has been evaluated in terms of forces, wheel wear, grinding ratio and specific power etc.

Experimental results have been obtained under dry cutting of mild steel with A24-R5-BFW wheel. Results indicate that there exists an optimum downfeed rate which gives maximum grinding ratio. The specific power criterion shows that there are two distinct regions below and above the optimum downfeed rate. Further, it indicates much freer cutting at lower feed rates and harder cutting at higher downfeed rates.

It is quite clear from the specific energy criterion that the temperature plays an important role causing wheel wear, resulting decrease in grinding ratio at lower and higher down-feed rates. For economic utilisation of wheel, optimum cutting condition should be chosen.

Size distribution analysis indicate that at lower downfeed rate it is mainly bond-post fracture and at higher feed rate grain fracture is more predominent. The optimum value is obtained with right combination of grain fracture and bond-post fracture.

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CHAPTER - I

1.1 Introduction

The grinding operation can be broadly classified into two categories - Finish grinding and Stock removal grinding. In finish grinding operations, the undeformed chip thickness is usually less than 3 μm, attritious wear is significant and wheels require frequent dressing. In stock removal grinding, on the other hand, the chip thickness is higher than 3 μm and wheels have self sharpening action.

The process of fine grinding has been studied quite extensively, stock removal grinding has not been much investigated. In the present work an experimental study has been carried out to evaluate the wheel performance and the important parameters that affect the Abrasive Cut-off operation, a stock removal process.

1.2 Abrasive Cut-off operation

The field of cutting high-strength and super-alloyed steels, including exotic materials, is reserved without any restriction for the high-speed and high-efficiency abrasive cutting-off operation. The cut is unaffected by thermal and mechanical influences and the cutting time is short. Since cutting operations in this field are hardly under the competing

influence of circular cold-saw, wheel cost is of secondary importance.

Abrasive cutting generally means the complete severance of a piece of material from a workpiece or length of material by means of an abrasive wheel. It is also used for slotting and partial cutting operations. The operation provides a smooth finish, accuracy of cut, speed of cut and invariably eliminates subsequent machining operations.

In the abrasive cut-off operation, resin-bonded wheels of coarse grains (Mesh Size : 24 to 60) and high hardness (P to T) are generally employed. The most common method of carrying out the operation is to have the wheel more radially through the work as shown in Fig. 1.1(a) and 1.1(b). The individual chips produced are, therefore, long. Occasionally, the wheel is also given a rocking with a circumferential motion when cutting bars of longer sections. The purpose of this is to decrease the chip length. The wheels used are normally 0.16 - 0.64 cm in thickness, and are 30 cm or more in diameter. The wheel speed or cutting speed used is relatively high, of the order of 3000 to 5000 m/min, to obtain high grinding ratio (Fig. 1.2(a)).

Abrasive cut-off operation is carried out under both dry and wet conditions. Resin bonded reinforced wheels are generally used for dry cutting, since coolant tends to weaken the bond. The peripheral cutting speed under dry cutting is

very important. For example a wheel running at a surface speed of 4575 m/min is about twice as efficient as a wheel operating at 2745 m/min. A 25X25 mm steel bar can be out in 2 seconds by dry cutting, whereas 4 seconds is usually required for wet cutting.

A liquid coolant is used in wet cutting, which reduces the workpiece temperature enormously. Rubber-bonded wheels without any reinforcement are used which are practically non-porous. Here the cutting speed is limited to about 2450 m/min in order to retain the coolant on the wheel surface in sufficient quantity to prevent excessive heating.

1.3 Previous Work

The primary consideration in the cut-off process is cost per cut or the cost per unit area that is severed. Secondary considerations are workpiece and wheel surface temperature, cutting force and power, wheel dynamics and stability and the mechanics of wheel wear.

Shaw et al. [1,2] have investigated the mechanics of abrasive cut-off operation and found the downfeed rate, d, to be the most important variable, which controls the wheel wear. They also found the contact length (l) between wheel and work (Fig. 1.1(b)) to be an important variable, since it has a major influence on the space available between the abrasive grains to accommodate the chips generated. In-sufficient space, they

suggested, causes excessive wheel wear or loading. Their experiments Fig. 1.2(b) show that the grinding ratio, G, (volume ratio of material removed and wheel wear) is low at low downfeed rates due to excessive temperature effects, increases to a maximum and then decreases for higher feed rates. This temperature and chip clogging effect gives rise to an optimum downfeed rate relative to wheel wear rate. In this study, the best performance was obtained (relative to cost per cut) with (a) wheels of the largest grain size (Mesh Size 20), (b) wheels of the hardest grade (grade R), (c) high values of wheel speed and (d) work having a short length (l) in the direction of cut.

Farmer and Shaw [3] also found that the importance of cutting force and the surface temperature of the wheel affect the rate of wheel wear and hence have bearing on the economics of the process. They suggested that in practice, a feed rate a little higher than one corresponding to the minimum wheel wear rate value should be chosen since this corresponds to minimum cost per cut. Singh and Shaw [4] gave methods of arriving at the cost optimum downfeed rate for the abrasive cut-off operation. Mitra et al. [5] have worked on optimisation of the cut-off parameters. They found that (i) the cost per cut increases with increasing value of total feed distance, (ii) for higher interface temperature, large wheel diameter should be used which

gives higher grinding ratio, (iii) the operating cost has little influence on cost per cut.

1.3.1 Undeformed chip thickness

The undeformed chip thickness, t, has been found to be an important variable affecting any grinding characteristics. It significantly influences the specific energy, wheel wear, surface finish, cutting temperature, etc. For abrasive cut-off, the undeformed chip thickness can be evaluated from [1,2]

$$t = \left(\frac{d}{vcr} \right)^{1/2} \qquad (1.1)$$

where t = undeformed chip thickness,

v = wheel speed,

d = downfeed rate,

c = number of active cutting points per unit area,

r = ratio of mean scratch width to mean scratch, depth, and

D = diameter of the wheel.

The value of c was determined by Backer, Marshall and Shaw [6], and Reichenbach et al. [7] by rolling the wheel over a soot coated plate and counting the number of contacts indicated on an enlargement made using the plate as a negative. This method

being somewhat crude gave a very high value of c. Shaw et al.[1,2] found that this method ignores the effects of surface waviness vibrations etc.

Malkin and Cook [8] determined c by counting the number of flats produced on the grinding wheel by lighting the wheel surface at a glancing angle and examining under a microscope. The total number of grains with wear flats divided by the viewing area gave the number of active grains per unit area.

$$c = \frac{n}{Lw} \tag{1.2}$$

where, c = number of active grains per unit area,

n = total number of grains with wear flats,

L = length of viewing, and

w = width of the active wheel.

The value of mean scratch width to mean scratch depth, r, was obtained by Shaw et al. [1,2] from a taper section of the workpiece. It was suggested [2] that its value varies between 8 to 15 and for 24 grain size the value of r is about 10. Lal and Shaw [9] have tried to eliminate this variable from the chip thickness equation. Their experiments show that the grain tip is approximately circular and is only a function of the grain size. They have suggested the following equation for evaluating chip thickness during surface grinding.

$$t = \frac{v}{Vc\sqrt{D(0.1\sqrt{g} - d_o)}} \tag{1.3}$$

where, t = undeformed chip thickness,

g = nominal grain diameter,

v = table speed,

V = wheel speed,

c = number of active grains per unit area,

D = wheel diameter, and

d_o = depth of cut.

Recently Jain [10] has derived an expression for the undeformed chip thickness for the abrasive cut-off operation on the basis of nominal grain size number(s) which does not take account of r term. For a 24R abrasive cut-off wheel his expression for t reduces to

$$t = 430.552 \left(\frac{d}{Vc} \times 10^6 \right)^{1/1.5} \mu in \tag{1.4}$$

where, t = undeformed chip thickness, μin

d = downfeed rate, ipm

V = cutting speed, ipm, and

c = number of active grains.

1.3.2 Specific Energy

The specific energy (energy required to remove a unit volume of material) in grinding can be found from force measurements and volume of metal removed. Shaw et al. [1] have measured the average force in cut-off operation and calculated the specific energy u , from the following expression

$$u = \frac{F_P V}{d l b} \tag{1.5}$$

where, F_P = tangential force,

l = length of cut, and

b = width of wheel.

Backer et al. [2,6] have shown that the specific energy $u \propto \frac{1}{t^n}$, where n is approximately a constant for a given type of grinding. For abrasive cut-off n is about 0.5. This decrease in specific energy with increasing chip size has been explained in terms of the size effect in metals based on the dislocation theory. It is also an established fact that forces and thus the specific energy are higher when machining with worn tools. In grinding it is found that the specific energy increases as the wheel wears [11].

1.3.3 Wheel wear

The wear of cut-off wheel is both physical and chemical in nature. Three types of physical wear have been observed. Attritious wear occurs at the grain workpiece contact surface and is gradual wearing away of the sharpness of the cutting points.

Fracture wear, on the other hand, is due to the removal of abrasive particles from the wheel either by partial fracture of grains or by fracturing away of the bond post. Fracture may take place when the grain or the bond posts holding the grains are unable to sustain the grain forces. Shaw et al. [1] and Backer et al. [2] have found that in abrasive cut-off operation grain fracture is more. They observed 70 to 80 % grain fracture for 24R wheel.

The common method for determining the volume of wheel wear [12, 13] has been to measure the change in wheel radius after certain number of cuts. The volume of wheel wear can thus be calculated from the equation.

$$V_w = \pi D h_g b$$

where, V_w = volume of wheel wear

D = diameter of wheel

h_g = reduction in wheel radius, and

b = width of the wheel.

This method of evaluating wheel wear could give very erroneous values for wear volume. This is because, the change in the diameter may be small compared to the size of the wear particles. On the other hand, wheel wear estimates from the collection of abrasive wear particles gives much more accurate values and in addition can provide an indication of the nature of the wheel wear.

1.3.4 Thermal Analysis

The mean temperature at the interface between the cut-off wheel and the workpiece is an extremely important parameter affecting the wheel performance. To determine this dominent parameter the cut-off process has been analysed by Farmer et al. [2]. They proposed a method of estimating the interface temperature using the following simplified assumptions :

1. The flow of heat to the workpiece that does not end up in the chips is negligible under equilibrium condition.
2. The rate of heat flow from the wheel face to the atmosphere is insufficient to cause any appreciable drop in wheel face temperature as the wheel rotates through the air. This means that the wheel face temperature is the same when it enters and leaves the workpiece.

3. The heat flow to the wheel is controlled by the amount of heat which may be dissipated at the wheel face to the atmosphere and not by the amount of heat which may be converted away from the interface by the wheel surface.

This analysis gives the following simplified equation for evaluating the interface temperature, T,

$$\frac{T_s \rho_c J}{u} = \left(1 + \frac{H}{{}_c d\, h}\right)^{-1}$$

where, T_s = interface temperature

J = mechanical equivalent of heat

ρ_c = volume of specific heat of work

H = heat transfer coefficient, and

h = depth of cut.

Eshghy [14, 15] has obtained expression for temperature at the interface in terms of dimensionless parameters. His result are dependent upon an important cutting parameter - energy per uni volume, which decreases with downfeed rate. Further, there exists a critical downfeed at which the temperature is maximum. His expression for temperature in dimensionless parameter is given as,

$$(T_s - T_a)\frac{\rho_c}{u} = \frac{0.60\ t_o^{0.3}}{\gamma + 1}[\beta^{-0.67} + 0.142\ \gamma^{0.44}]$$

where, T_s = interface temperature,

T_a = atmosphere temperature,

t_o = dimensionless time, and

β and γ = dimensionless parameters.

1.4 Present work

In abrasive cut-off operation, the optimum utilization of cut-off wheels can best be achieved if the nature of their performance and wear characteristics and the factors that affect these characteristics are understood and applied. The objective of this process is to produce a workpiece to a close size tolerance, with surface finish held within a narrow-zone and good surface integrity, at minimum cost. In order to do this, effective control of the many variable involved in the process is required. In the present investigation, an experimental study has been made to identify the important variables in abrasive cut-off operation and to determine how they are related to each other. Emphasis will be put on those variables which affect the grinding ratio, forces and specific energy, surface roughness cutting temperature, etc. so that the process can be optimized.

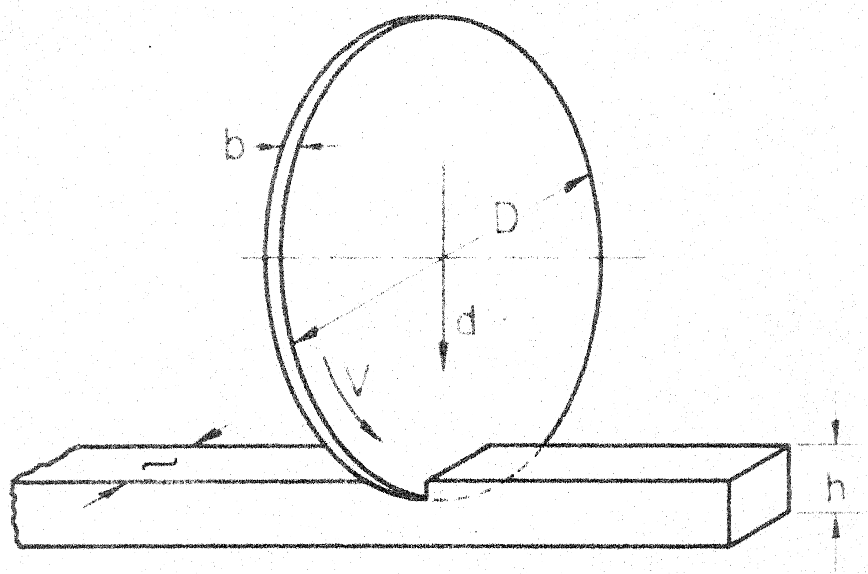

Fig. 1.1 (a) Abrasive cut-off process

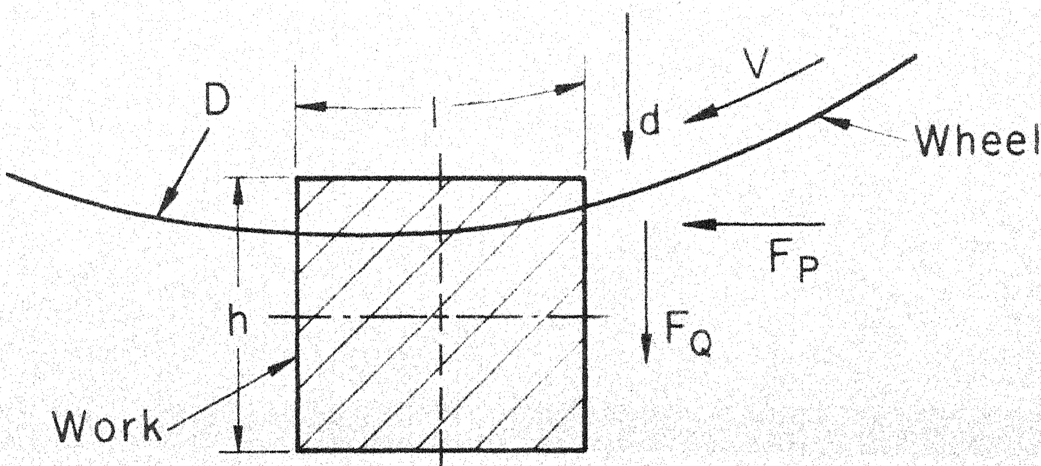

Fig. 1.1 (b) Cut-off schematic

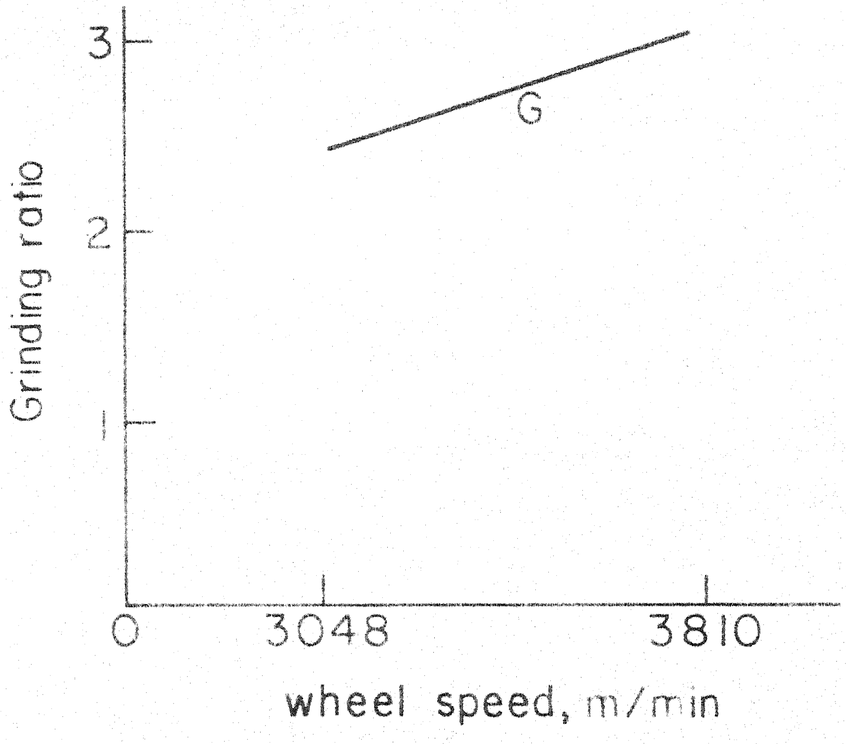

Fig.1.2 (a) Grinding ratio, G vs wheel speed

[After Shaw(2)]

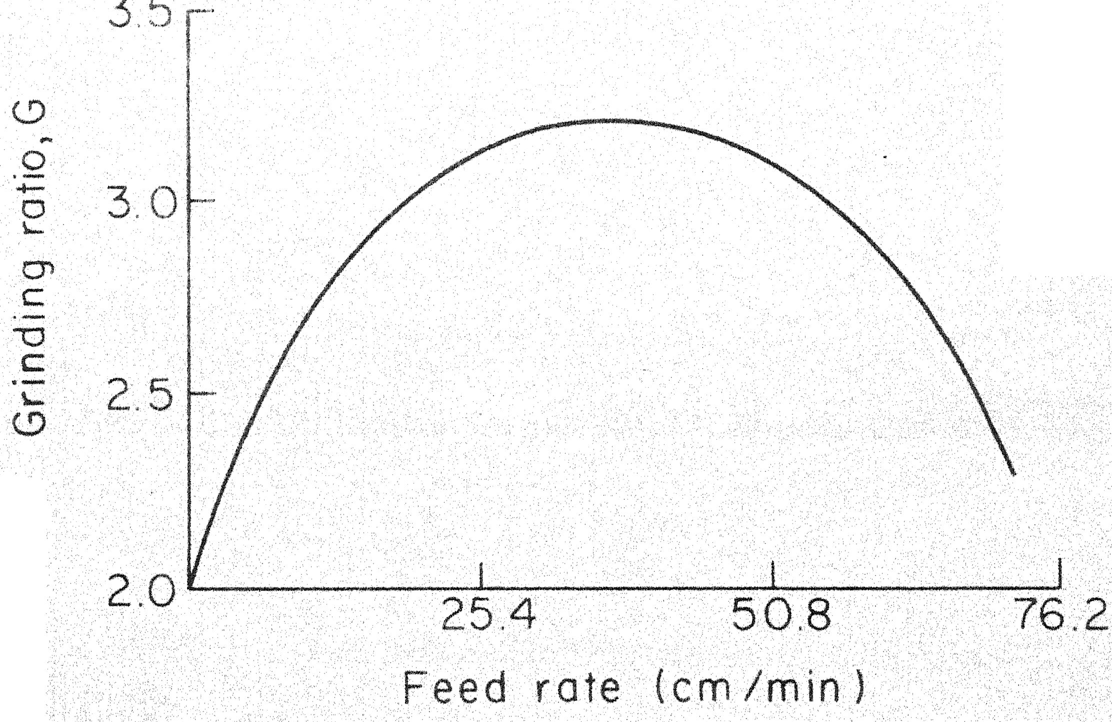

Fig.1.2 (b) Grinding ratio, G vs. feed rate, d

[After Shaw (2)]

CHAPTER - II

EXPERIMENTAL SET-UP

2.1 Abrasive Cut-off machine

An automatic, hydraulically operated swing frame, heavy duty abrasive cut-off machine type FAP-10 manufactured by Harve Limited, Bombay, was used for the experiments. The specification of the machine are given in Appendix 2.1.

2.2 Abrasive Cut-off wheels

Abrasive cut-off wheels specially manufactured for these experiments were supplied by M/s Universal Carborundum Limited, Madras. The specification of the wheels used for the experiments was A24-R5-BFW with Resin bonded reinforcement. This wheel is usually used for cutting ferrous materials under dry conditions.

2.3 Work material

A mild steel bar of 25 mm square section was used as a test piece. The hardness of workpiece speciman was 60 R_B.

2.4 Measurement of forces

In the abrasive cut-off operation, normal and tangential components of force are of main interest. These

forces were measured using an extended octagonal ring type two component semi-conductor strain guage dynamometer. Wheatstone bridge circuits were used for measuring the two force components independently. The dynamometer was calibrated using dead weights upto 50 kg in the normal direction and upto 30 kg in the tangential direction. The calibration curves are shown in Fig. 2.1. The interaction between the force components was less than 2 %. The output from the dynamometer was recorded on a galvanometric type recorder, manufactured by M/s Encardio-Rite, Lucknow.

2.5 Measurement of vibration

The relative amplitude of vibration was measured during the cut-off process. A self generating electrodynamic sensor type vibration pick-up was used for these experiments. The pick-up generates the electrical output without actual contact with the vibrating mass. The pick-up was mounted very close to the workpiece and the output signal after preamplification was recorded on a galvanometric type recorder. The initial value of the amplitude of vibration, that is when the wheel is not cutting but the machine is operating, was taken as the zero reading.

2.6 Measurement of instantaneous cutting speed

To determine and record the instantaneous wheel speeds while cutting, a A.C. tachometer generator ("STANDCO"

Generating voltage at 1000r.p.m. : 50 Volts, Herman H. Sticht Co., Inc., New York, U.S.A.) with switching unit was used. The A.C. tachometer generator was coupled to the cut-off wheel shaft (Fig. 2.2) and the signal was fed to the switching unit consisting of a step-down A.C. transformer, a full wave rectifier, an amplifier and a low pass second order filter to ensure quick response. The D.C. output from the low pass filter was fed for recording the instantaneous cutting speeds. The schematic arrangements and the circuit diagram are shown in Figures 2.3 and 2.4.

2.7 Measurement of downfeed rate

The actual downfeed rate for each cutting test was determined from the chart speed of the recorder tracing the force pattern. The chart speed used was 100 mm/sec., i.e., cutting time of 1/100th of a second could be recorded. The downfeed rate, when not cutting was measured by checking the time for a set length of vertical oscillation of the wheel. This enabled the drop in down feed-rate during actual cutting to be evaluated.

2.8 Evaluation of wheel wear

Wheel wear has been evaluated in two ways.

2.8.1 From reduction in wheel radius

A micrometer of least count 0.0025 mm was mounted vertically on the wheel casing. Initial reading was taken before a cut. After five successive cuts at the same down feed-rate the reduction in wheel radius was measured.

2.8.2 From debris collection

Debris which composed of iron particles and abrasive grits, generated during the cut-off process were collected in a debris-collector, which completely enclosed the cutting zone. The inside walls of the debris collector was coated with white petrolatum grease to collect the chips and the grains that were generated. The grease along with the debris were easily removed. The grease was then separated by dissolving in boiling tricholo-ethylene. Most of the iron particles were removed from the debris by boiling in aqua-regia acid solution and the remaining iron particles, if any, were removed with the help of a magnet. The abrasive grits thus obtained were weighed on a semimicro-balance with an accuracy of 0.001 mg.

For evaluating the grinding ratio, the debris which contained iron chips and grits was weighed before dissolving in aqua-regia acid solution. The corresponding material removal rate is also obtained from the weight of the iron-chips.

2.8.3 Size distribution

To determine the size distribution of the wear particles, the grains collected were screened through a series of test sieves (size : 24-120). The grains passing through each of the test sieves were separately weighed and the corresponding percentage to the total weight was calculated.

2.9 Measurement of Grain density

The number of active grains was evaluated by observing the section of the active periphery of the wheel under a Carlzeiss optical Sterio-microscope. Illumination of the surface at a glancing angle helped considerably in locating the active cutting grits. A magnification factor of (X50) was found to be sufficient for distinguishing the active grains.

The counting of active grains was done at four different sections on the wheel periphery. The number of grains were counted over a travel length of 2.878 m and the counting was repeated at least three times and the average value was taken.

To check the sterio-microscopic results, the wheel profile projection method was also used to determine the active grains. The instrument used was optical projector MP320 manufactured by Carlzeiss. The results obtained on optical projector were in good agreement with the sterio-microscope observations.

2.10 Measurement of surface roughness

After each cut, the surface roughness (finish) of the cut surface of the workpiece was measured using a profilometer (Mototrace, Micrometrical Mfg. Co., U.S.A.).

2.11 Cutting conditions

The experimental conditions used in this series of tests are given below.

Wheel : A24-R5-BFW

Wheel Speed (V) : 3167 m/min

Wheel Diameter (D) : 350 mm

Width of Wheel (b) : 3 mm

Down feed-rate (d) : 5 to 60 cm/min

Workpiece : Mild steel; 60 R_B; 25X25 mm square section.

Cutting fluid : Dry.

2.12 Experimental procedure

The workpiece was clamped on the vice fitted on the dynamometer. The down feed-rate was set at the desired value and then the wheel was started. Before each experiment, the machine along with its hydraulic system, the dynamometer and other electrical equipment were allowed to warm-up for about

ten minutes for stability in their working characteristics. Finally the cut was made and corresponding forces, vibrations, instantaneous wheel speed and down feed rate were recorded on a strip chart recorder. After five cuts at the same down feed-rate the machine was stopped and reduction in the wheel diameter was measured with the help of a micrometer (least count 0.0025 mm) and wear particles were collected. The wheel swas examined under the sterio-microscope for estimating the number of active cutting points. The cut surface of the workpiece was also traced using a profilometer and the surface roughness values were obtained. The wear particles were subsequently analysed to obtain the wear particle size distribution. The complete experimental set-up is shown in Fig. 2.5.

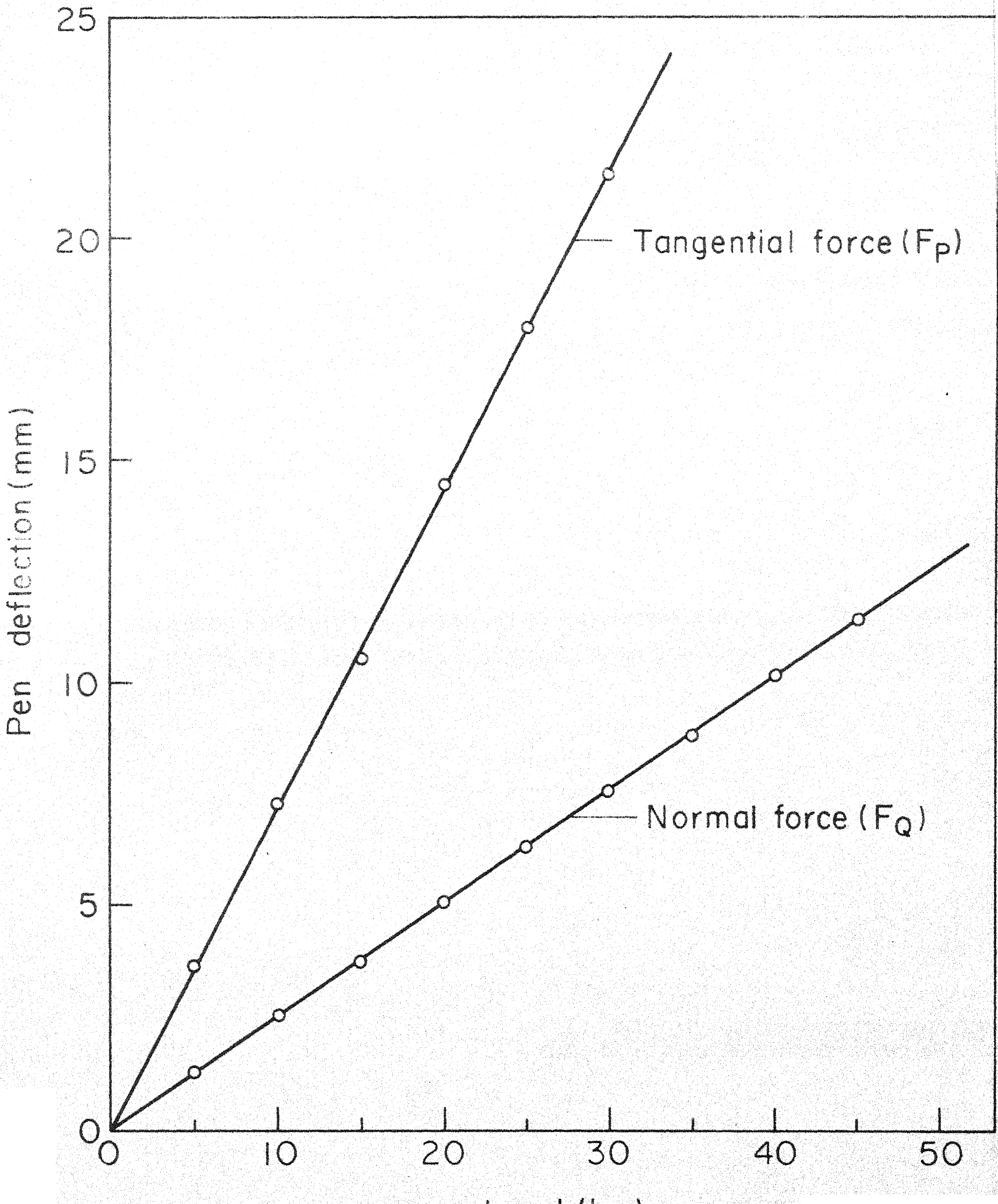

Fig. 2.1 Force calibration curve

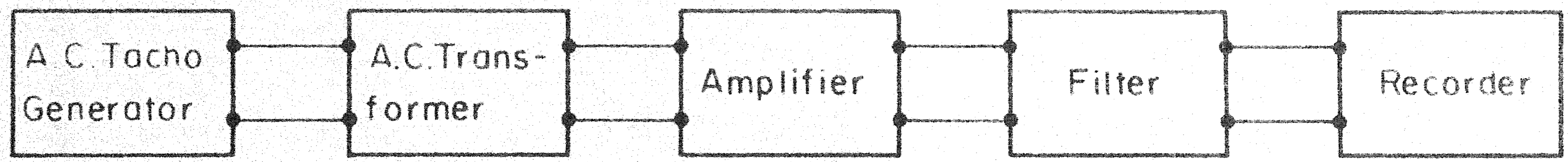

Fig.2.3 Schematic diagram of instantaneous wheel speed measurement

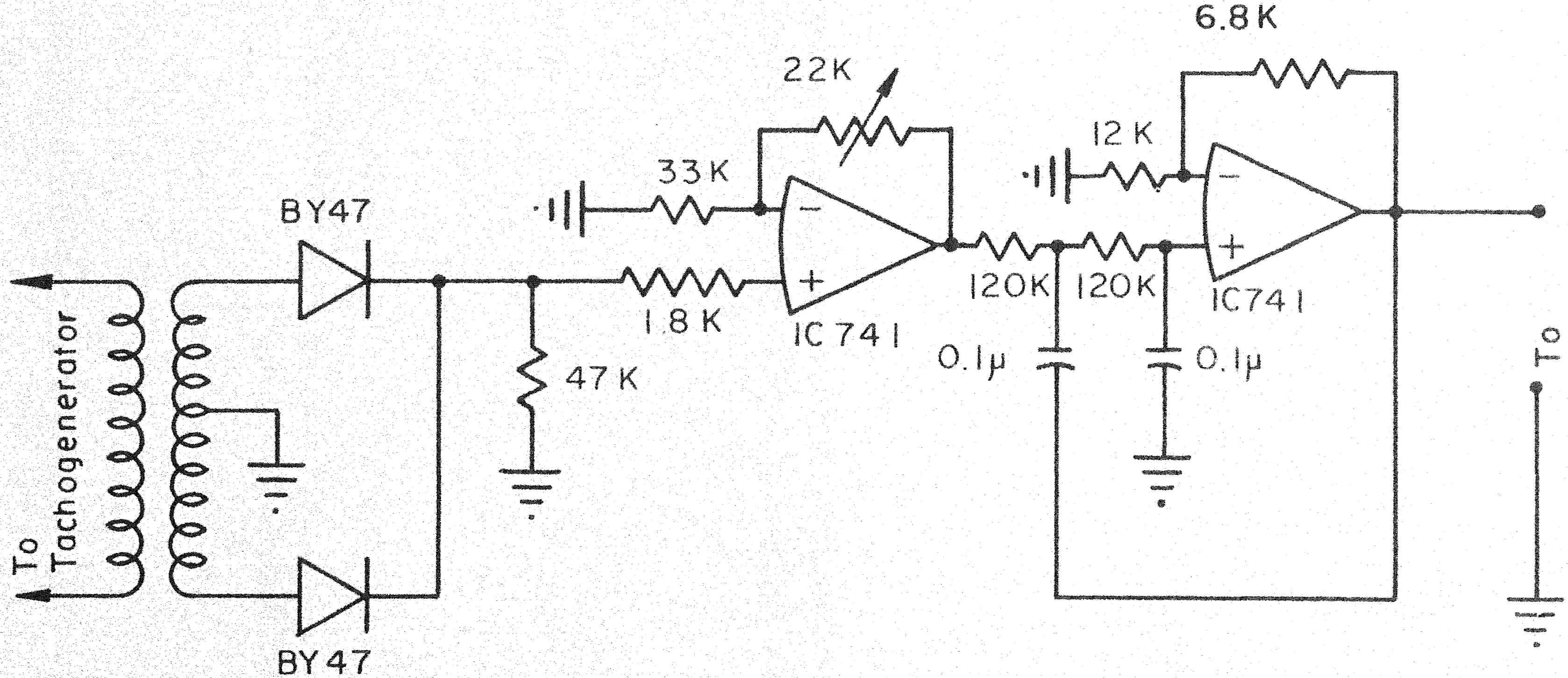

Fig.2.4 Circuit diagram of switching unit

CHAPTER - III

RESULTS AND DISCUSSION

3.1 Results

In this experimental study of abrasive cut-off operation, the effects of cutting conditions on output parameters like forces vibrations, wheel wear, material removal rate, surface roughness, etc. have been investigated. The input parameters such as wheel speed and downfeed rate have been measured during cutting. It has been suggested [1,2] that their set values are considerably reduced during wheel-work interaction.

The average reduction in the wheel speed, ΔV at different downfeed rate is plotted in Fig. 3.1. This average cutting speed has been accounted for the calculation of output parameters. A typical curve Fig. 3.2 shows the variation in cutting speed with cutting time for a particular downfeed rate. The actual downfeed rate at the time of cutting was obtained from the recorded force pattern. The reduction in the downfeed rate against actual downfeed rate is plotted in Fig. 3.1. It is seen that the reduction Δd increases with increased downfeed rate.

The downfeed rate is an important parameter in abrasive cut-off operation and has a strong bearing on the normal force, F_Q

and the tangential force, F_P. These forces have been measured with the help of a strain gauge dynamometer and the recorded values have been plotted against the actual downfeed rate in Fig. 3.3. These forces are seen to increase with downfeed rate. The force ratio F_P/F_Q has also been plotted in Fig. 3.4. It is clear that, this ratio varies from 0.4 to 0.6 with a mean value is about 0.5.

A typical curve Fig. 3.5, showing the variation in relative amplitude of vibration with downfeed rate has been plotted to check the wheel deflection and stability at higher downfeed rates.

The metal removal rate M_R^*, is an important parameter in abrasive cut-off process and has been evaluated from

$$M_R^* = d\ l\ b \tag{3.1}$$

and plotted against downfeed rate d in Fig. 3.6.

The wheel wear has been evaluated from the reduction in wheel radius and also from the grains obtained in the debris. The radial wheel wear has been plotted against downfeed rate in Fig. 3.6. It is clear from the graph that wear is not a direct function of downfeed rate.

The grinding ratio obtained from both radial wheel wear and debris are plotted against downfeed rate in Fig. 3.7, which

shows an optimum value of feed rate for maximum grinding ratio.

The variation in workpiece surface roughness and active grain density with feed rates have also recorded and these are plotted in Fig. 3.12 and 3.13.

3.2 Discussions

The average reduction in wheel-speed increases with actual downfeed rate (Fig. 3.1). This percentage reduction in wheelspeed varies between 6-10 % . A typical curve (Fig. 3.2) indicates that the speed drops at the start of the cut and then remains more or less constant for almost 60 % of cut. At the end of the cut the speed however, decreases drastically. This is because there is little workpiece beneath the wheel at the end of the cut and the temperature rises rapidly causing the uncut metal to expand thermally [1,2]. This forces the cut surfaces to rub against the sides of the wheel causing decrease in the wheel speed.

The reduction in average downfeed rate (Fig. 3.1) indicates that Δd varies between 15 to 35 %. This fact was also confirmed by Shaw et al. [1,2]. Since the variation in downfeed rate and wheel speed during actual cutting was significant, the measured values and not the set values have been used in all subsequent calculations.

The recorded force trace also shows that the tangential force F_P increases appreciably at the end of cut. This is because of the rigid clamping of both ends of the workpiece and the thermal expansion of the uncut metal, as mentioned earlier. Examination of the force trace and wheel-speed drop pattern indicates that the sudden drop in wheelspeed and rise in force occurs around the same time. Examination of the cut surface frequently showed burn spots near the center of the cut surface indicating excessive rubbing action and increased temperature. These effects do not seem to have any influence on the normal component of force F_Q.

Fig. 3.3 shows the variation in the forces with downfeed rate. It appears that the behavior of the wheel changes at around 30 cm/min feed rate when the slope of the curve changes significantly. Beyond this point the corresponding increase in forces with increase in feed rate is quite significant and may in term affect the wear mechanism. Tangential force F_P has been plotted in Fig.3.8 against material removal rate calculated using equation (3.1). Here also two distinct regions are observed, above and below 30 cm/min feed rate.

A parameter specific power (u_s) defined as the ratio of power to the material removal rate, has been sometimes used for evaluating wheel performance [16]. This can be evaluated from

$$u_s = F_p V / d\ l\ b \qquad (3.2)$$

which has the same dimensions of specific energy.

Since power required for cutting is a function of tangential force, the slope of tangential force versus metal removal rate curve gives specific power. This is specific because it describes the cutting action over the complete range of testing. In Fig. 3.8, below d = 30 cm/min, the slope is 0.12 HP/cm^3/min indicating a much freer cutting, while above d = 30 cm/min the specific power increases to 0.52 HP/cm^3/min. Obviously, something happens around d = 30 cm/min to cause the wheel to cut much harder, that is the wheel tends to behave like a somewhat harder wheel. This is also seen in Fig. 3.9 where specific power is plotted against material removal rate. Initially the specific power decreases indicating much freer cutting and then it increases indicating less efficient cutting. Here also the break point of the two regions appears to be around d = 30 cm/min.

From the experimental force data, the specific energy u values have also been calculated, and plotted in Fig. 3.10 against undeformed chip thickness (t) values derived from equation (1.4). The actual d and V values have been used for evaluating u and t. Initially the specific energy decreases

with increasing chip thickness upto a certain value, then around d = 30 cm/min it appears to increase with increasing chip thickness. Earlier workers [1,2] have found the specific energy in grinding to decrease with increase in t. In this respect the results does not agree with published results.

In abrasive cut-off operations, the temperature plays a very dominant role, since the temperature is mainly a function of specific energy, at low downfeed rates the temperature is likely to be high. This is quite evident from the deep burn and burr marks observed throughout the cut surface. At very low downfeed rates (less than 11.76 cm/min), small radial cracks developed in the outer wheel periphery due to thermal energy accumulation. In a few cases, large pieces spalled from the edge of the wheel while cutting. This temperature, however, decreases as the feed rate is increased upto a certain value and then starts to increase again (Fig. 3.11). This figure has been taken from the theoretrical analysis of Jain [10]. Thus there is a certain feed rate where lowest (optimum) temperature exists. Wheel performance is affected significantly by the interface temperature and this affects the wheel performance. The variation in specific power (and specific energy) with downfeed rate shows similar trend.

The fact that the wheel performance gets affected is also observed in Fig. 3.5 which shows how the amplitude of

vibration increases with increasing downfeed rate. Excessive vibrations is indication of harder cutting and generally results in poor surface finish. When the surface roughness values are plotted against feed rate (Fig. 3.12), it clearly indicates that beyond a certain feed rate the resulting surface quality deteriorates. Fig. 3.12 also indicates the existance of an optimum surface roughness value corresponding to a feed rate of around 35 cm/min. On either side of this value the surface finish deteriorates because of the wheel rubbing against the cut surface with increased interface temperature.

The active grain density (c) also decreases at higher feed rates (Fig. 3.13) and this will also result in inferior surface finish.

Fig. 3.6 indicates that the material removal rate is directly proportional to downfeed rate. This means whatever material has been fed is completely removed during cutting. The wheel wear pattern is however, very different. It shows that the wear is maximum at lower and higher feed rates. There exists an optimum wheel wear corresponding to a certain downfeed rate (around 30 cm/min). The grinding ratio curve (Fig. 3.7), therefore, indicates an optimum value. A possible explanation for this grinding ratio curve was given by Shaw et al. [1,2]. They suggested that at low downfeed rates, the time for cutting is more so the thermal penetration into the wheel is high

resulting in increased wheel wear. At higher downfeed rates it is the chip crowding effect that results in high wheel wear. While the temperature effects seem justified, the argument regarding chip clogging does not seem to be valid. During the experiment, the wheel surface was observed under microscope and hardly any trace of chip clogging or loading in the voids appeared. The abrasive cut-off wheel structural model [10], also indicate that sufficient space is available for accommodating the chips during cutting. Further, the grain density plot (Fig. 3.13) indicates that at higher downfeed rates the grain density decreases because of harder cutting. This decrease in the grain density would also provide additional space to accommodate chips at higher downfeed rate. Thus, loading does not appear to be the factor affecting wheel wear at higher downfeed rate. The specific power criterion seems to indicate that it is the temperature which affects the wheel performance at higher downfeed rates also. Temperature models[14, 15] clearly indicate that the temperature is higher on either side of the optimum downfeed rate.

The size distribution of the wear particles is shown in Fig. 3.14. The cumulative percentage of the abrasive material remaining on each screen size at different downfeed rates are also plotted against sieve size in Fig. 3.15. It is evident that more grains are fractured as the downfeed rate is

increased. It may also be seen that a smaller percentage of grains remains on the nominal screen size (Mesh size 24). From Fig. 3.16 it is clear that the percentage bond-post fracture decreases as downfeed rate increases. The percent bond-post fracture has been evaluated in a similar manner as given by Pande [17].

These observations seem to indicate that the performance of the wheel is affected on either side of the optimum value due to increase in temperature. At lower downfeed rates excessive bond-post fracture results in low grinding ratio. This in tern will cause the wheel behave somewhat softer. On the other side of the optimum, i.e., at higher downfeed rates the grain fracture is excessive causing the wheel to behave little harder. The optimum value is obtained with right combination of grain fracture as well as bond-post fracture.

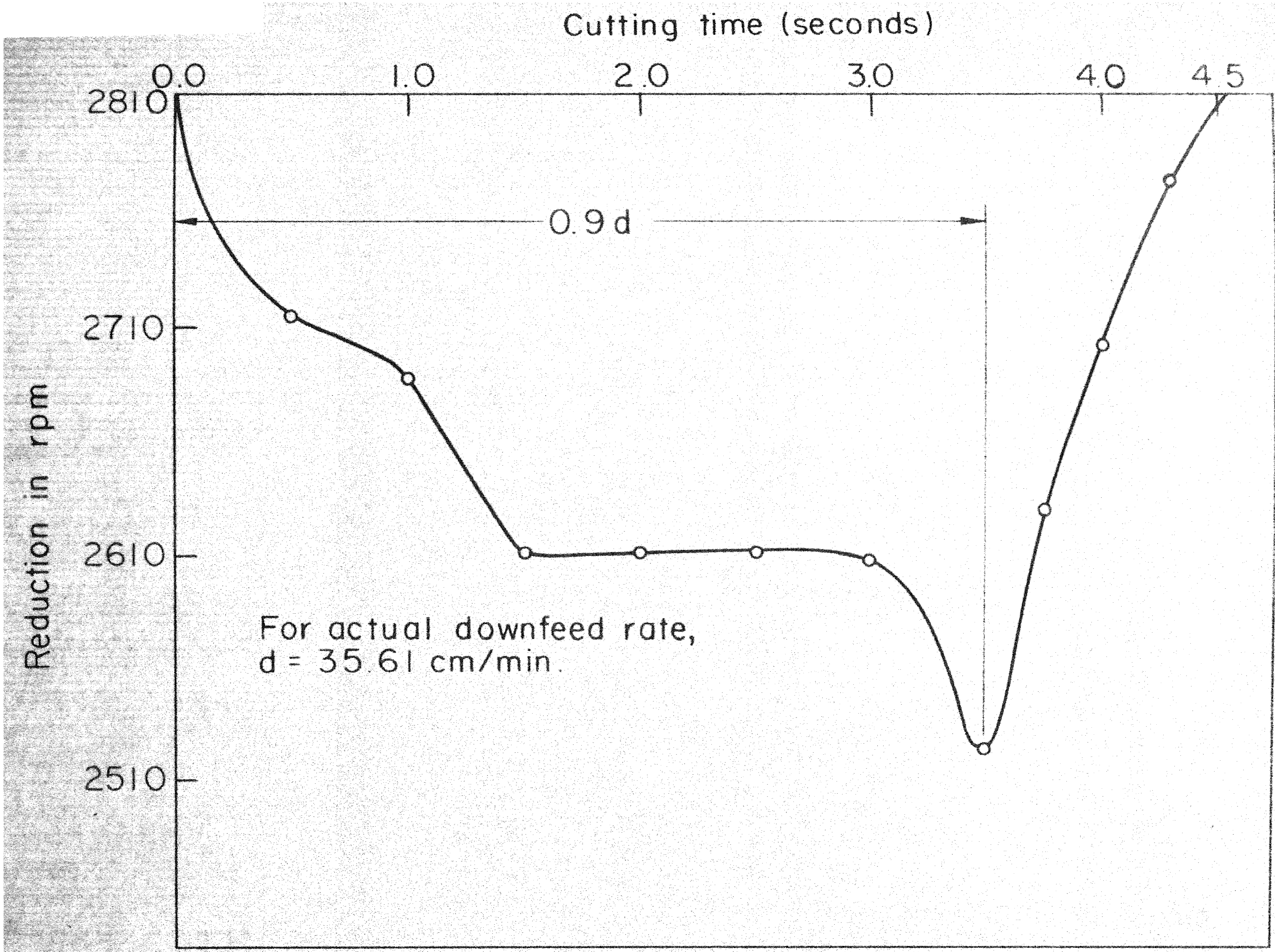

Fig.3.2 Variation of wheel speed with cutting time at a particular down feed rate

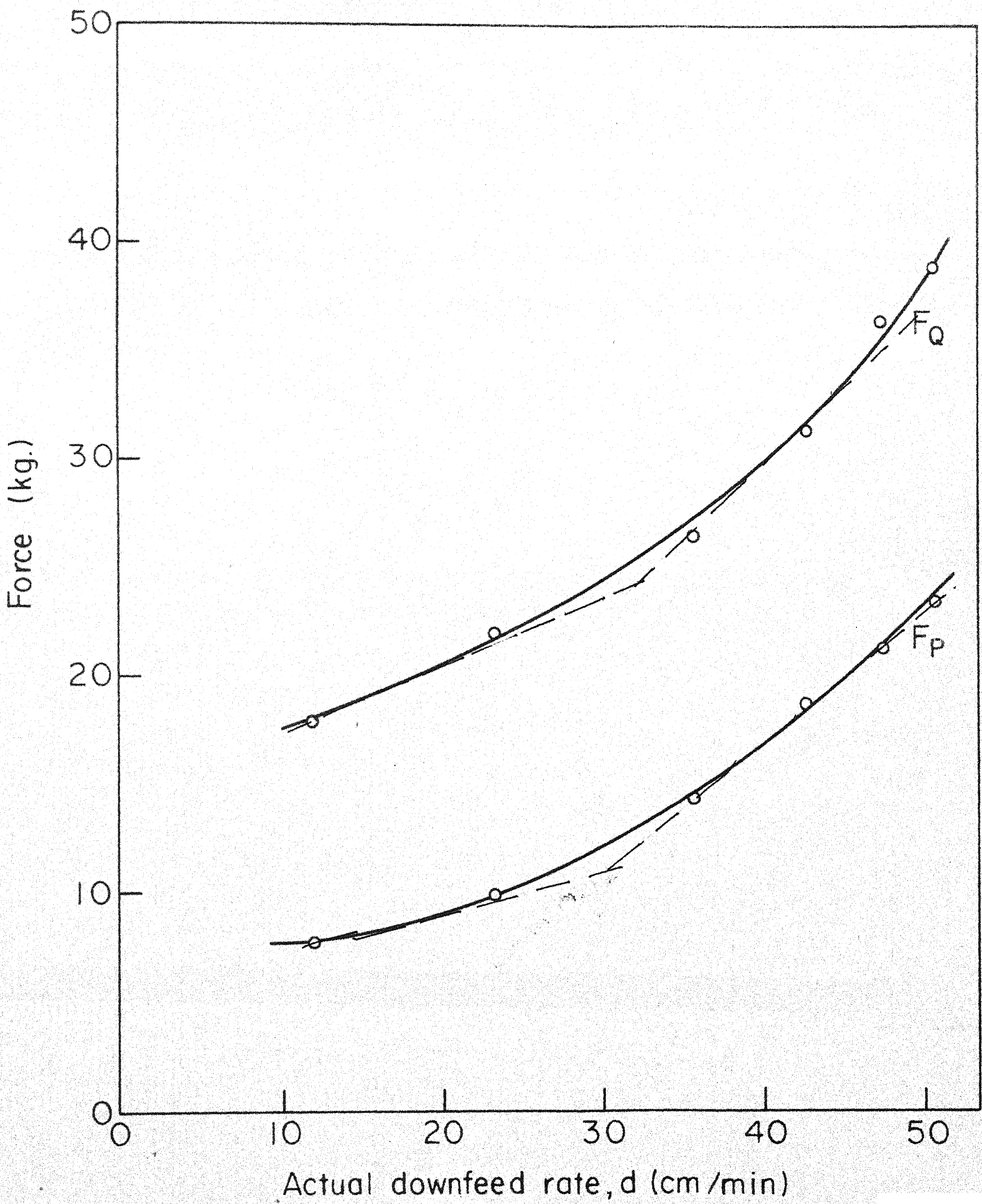

Fig.3.3 Variation of grinding forces with downfeed rate

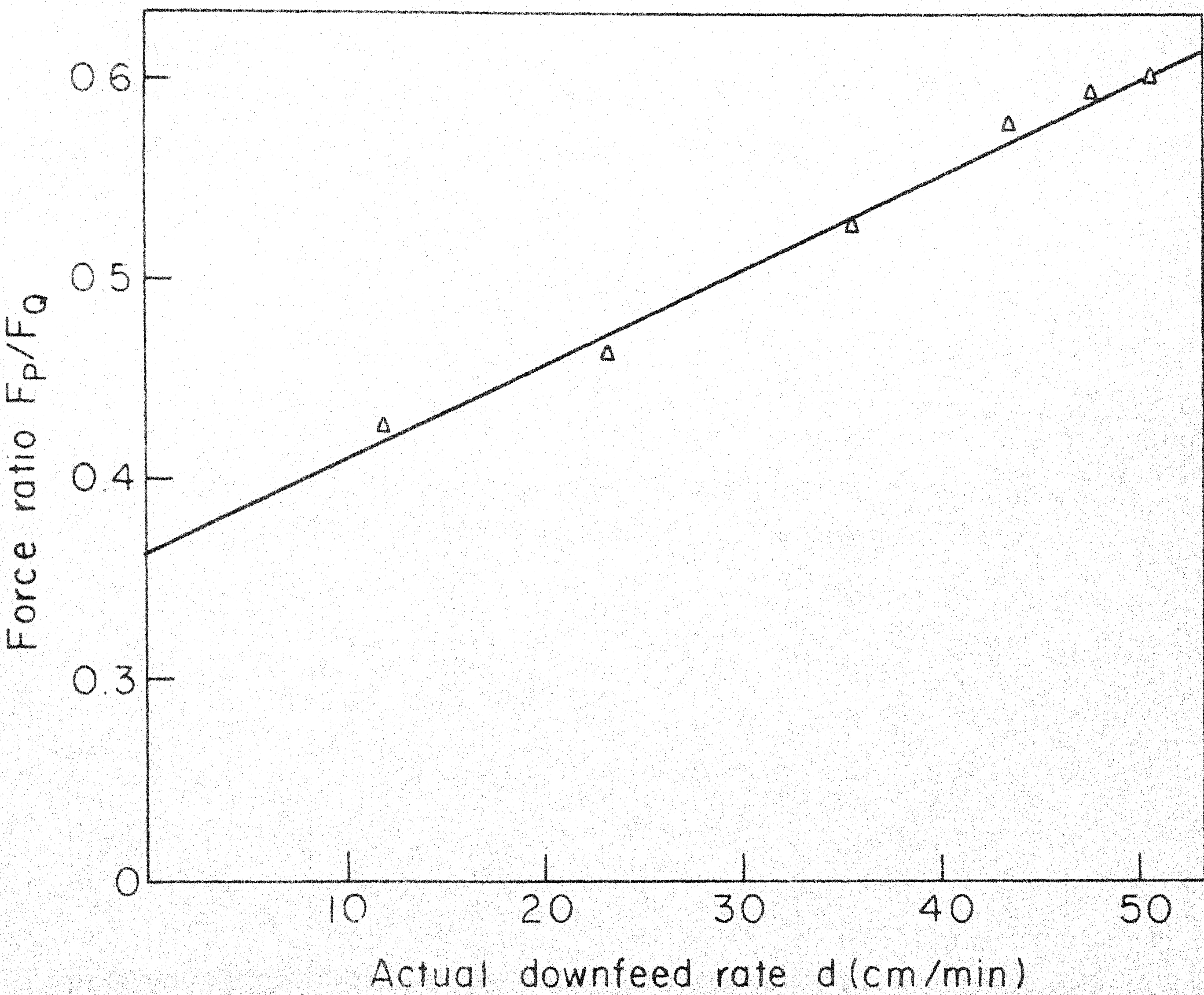

Fig.3.4 Variation of force ratio F_P/F_Q with downfeed rate

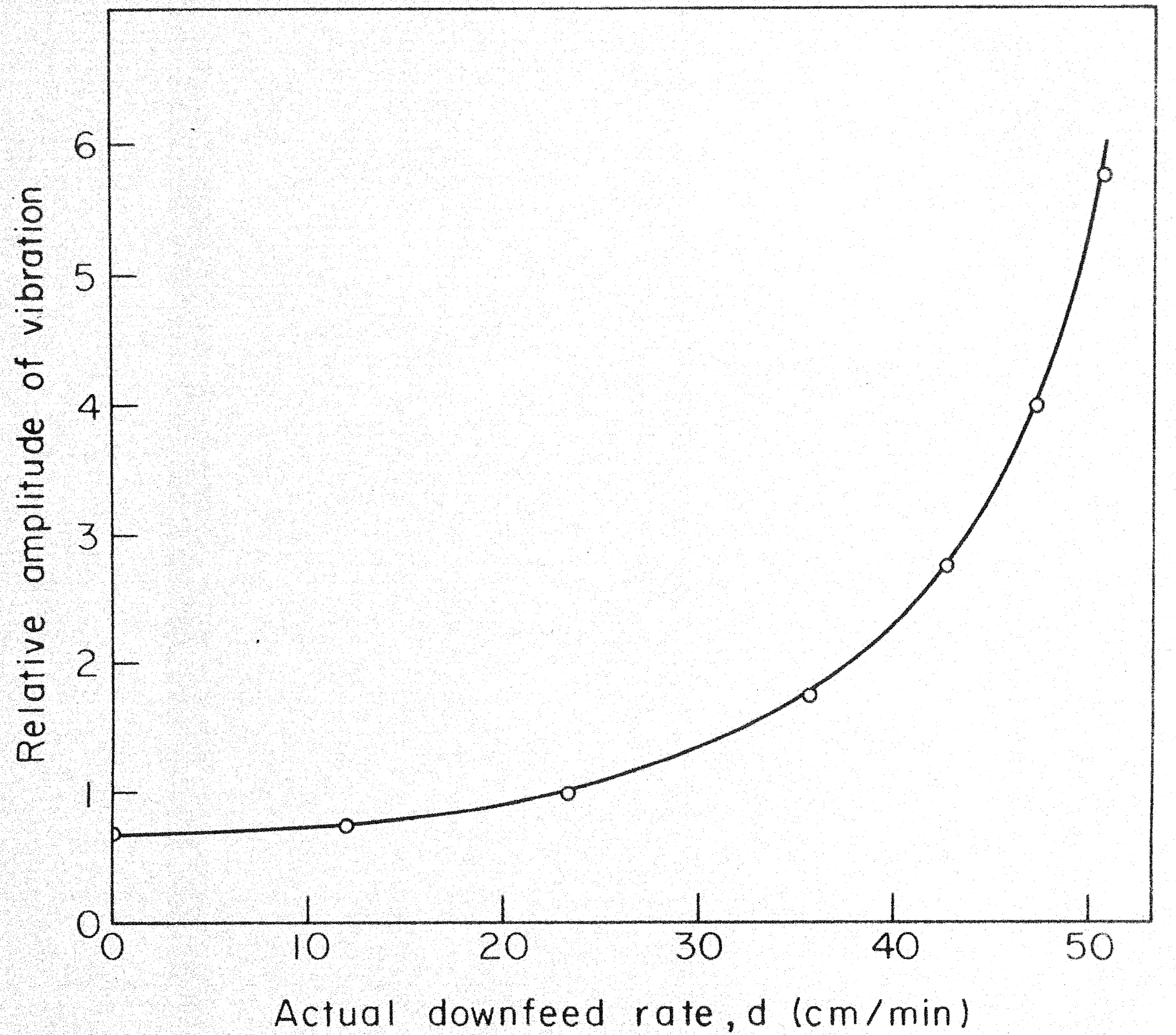

Fig.3.5 Variation of relative amplitude of vibration with downfeed rate

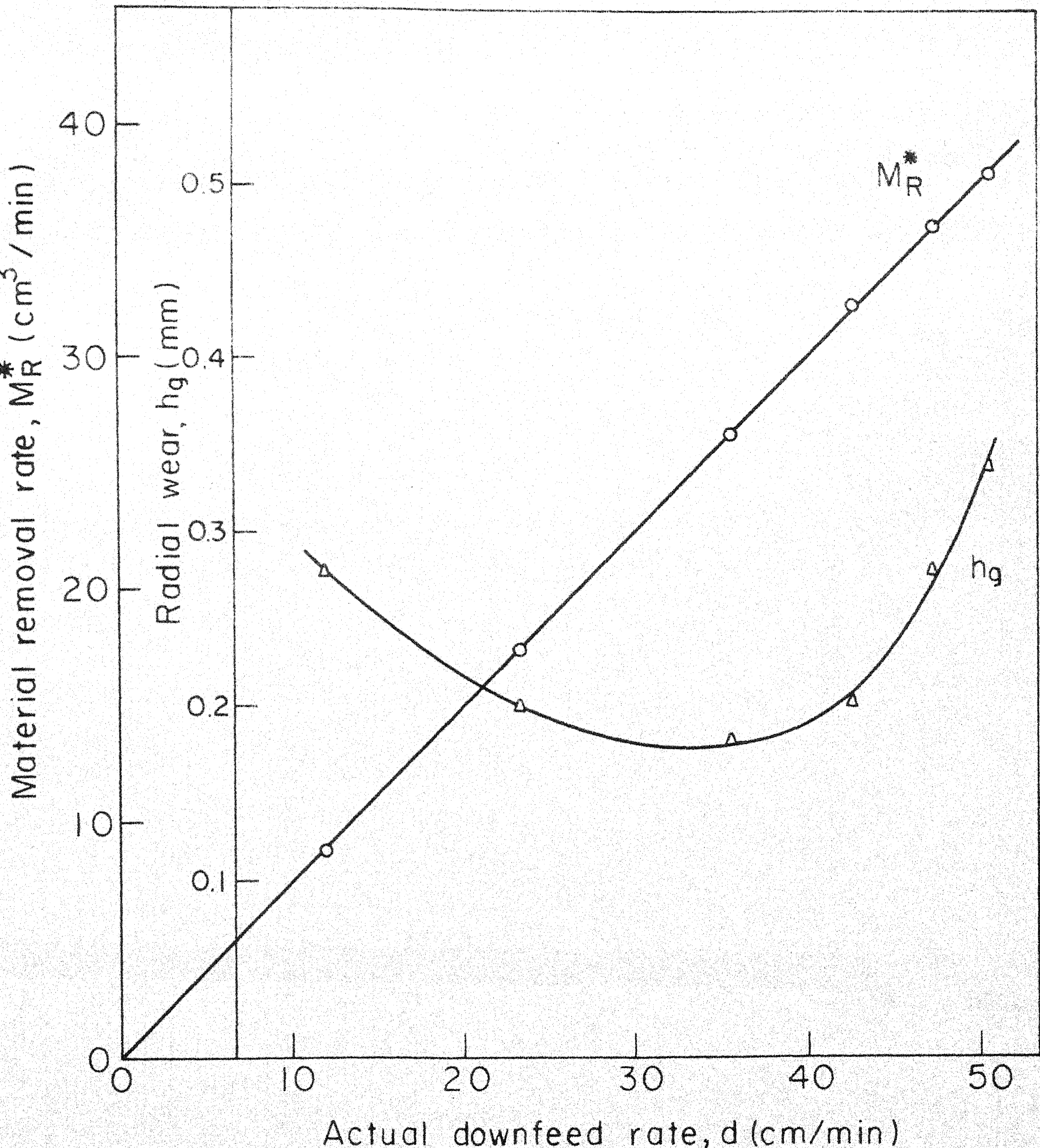

Fig.3.6 Variation of metal removal rate and radial wheel wear with downfeed rate

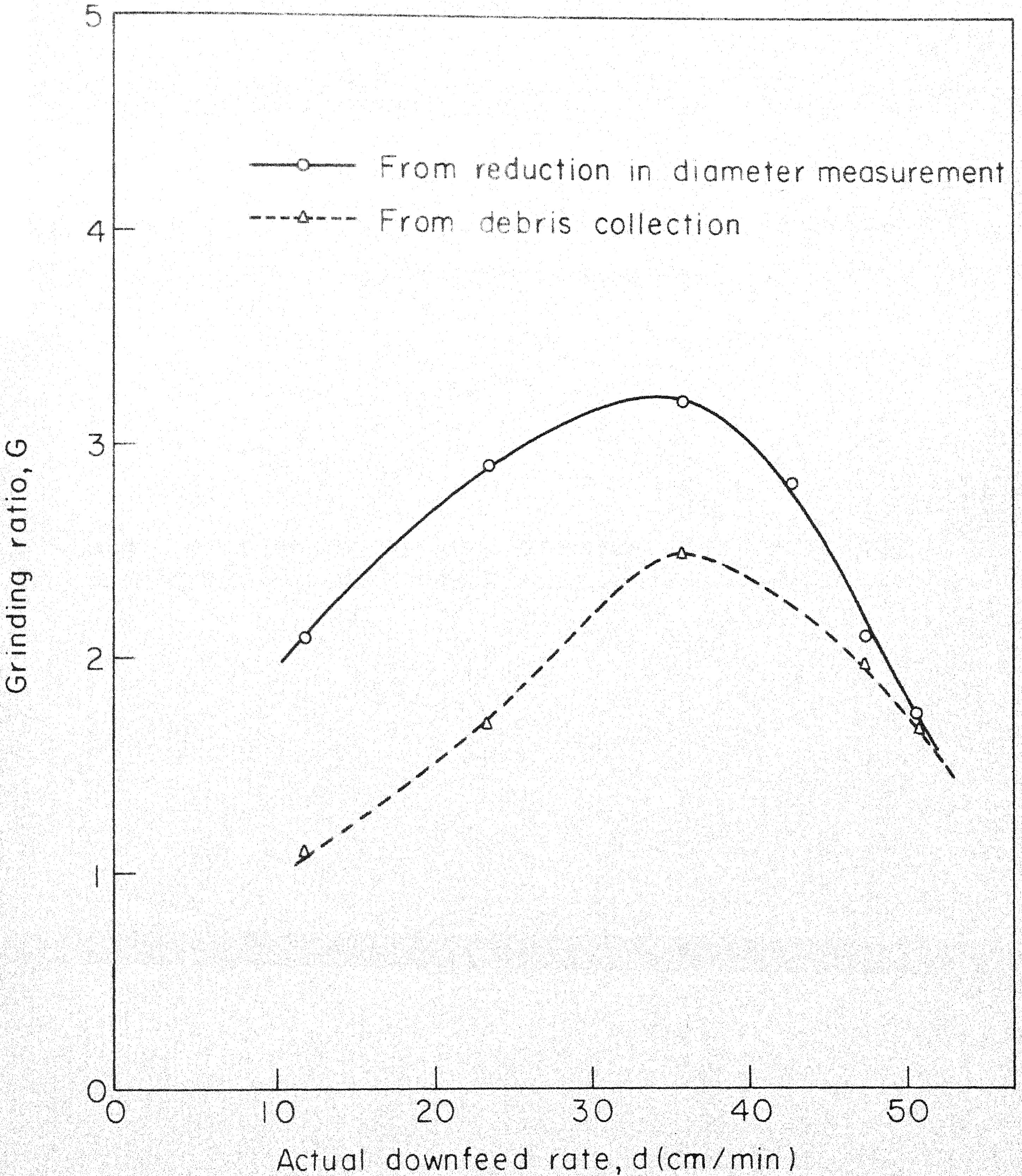

Fig.3.7 Variation of grinding ratio with downfeed rate

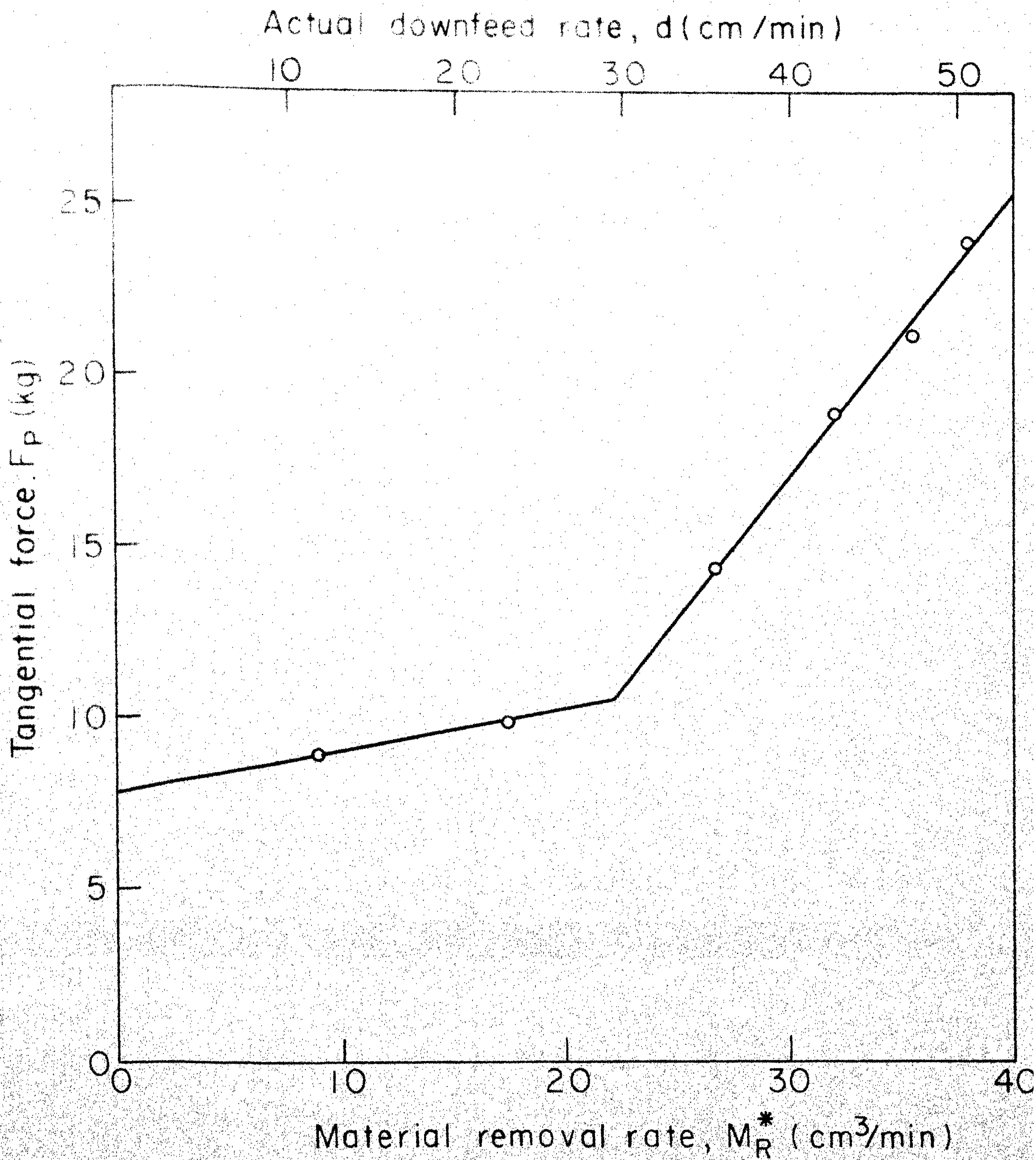

Fig.3.8 Variation of tangential force with metal removal rate

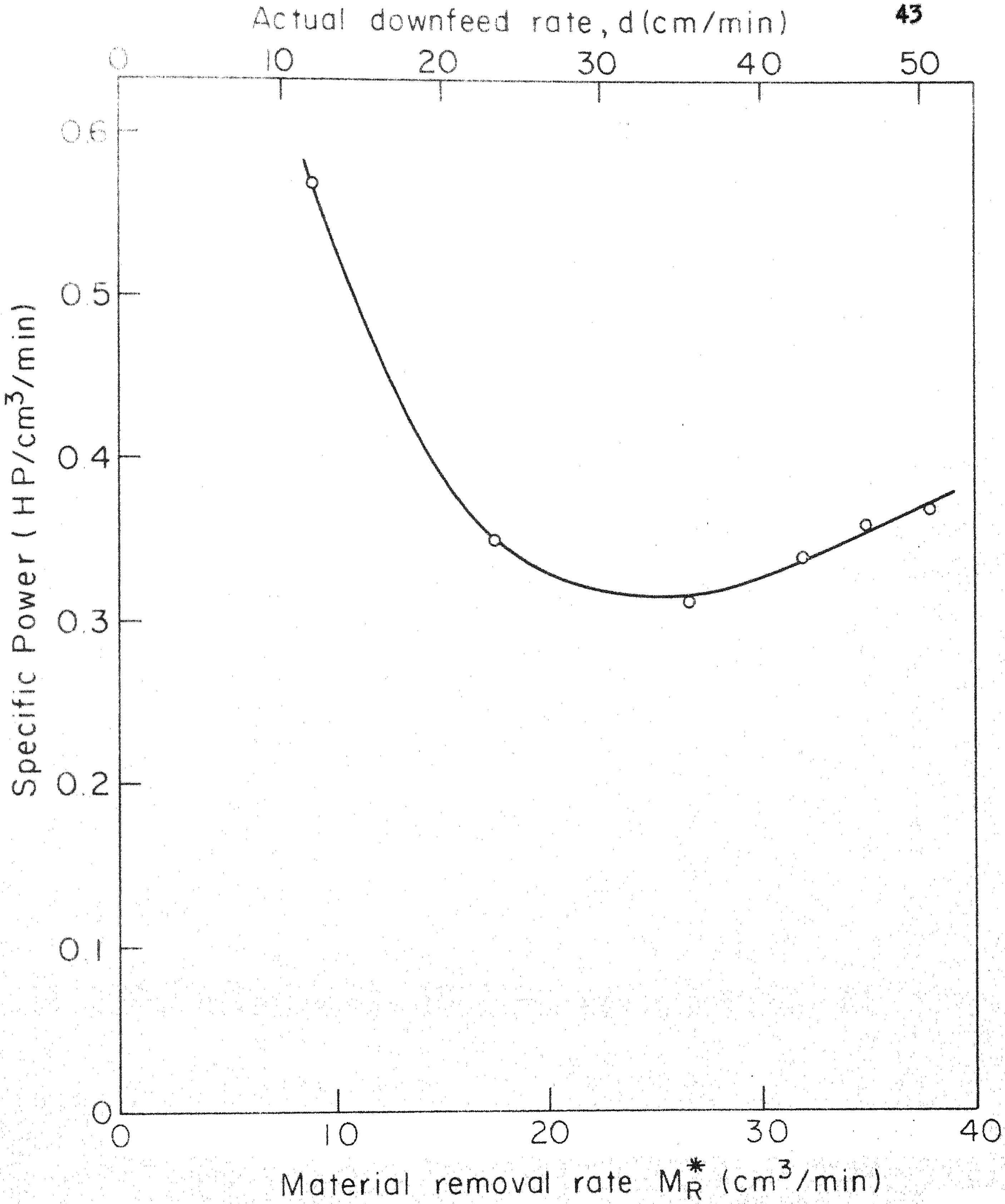

Fig.3.9 Variation of specific power with metal removal rate

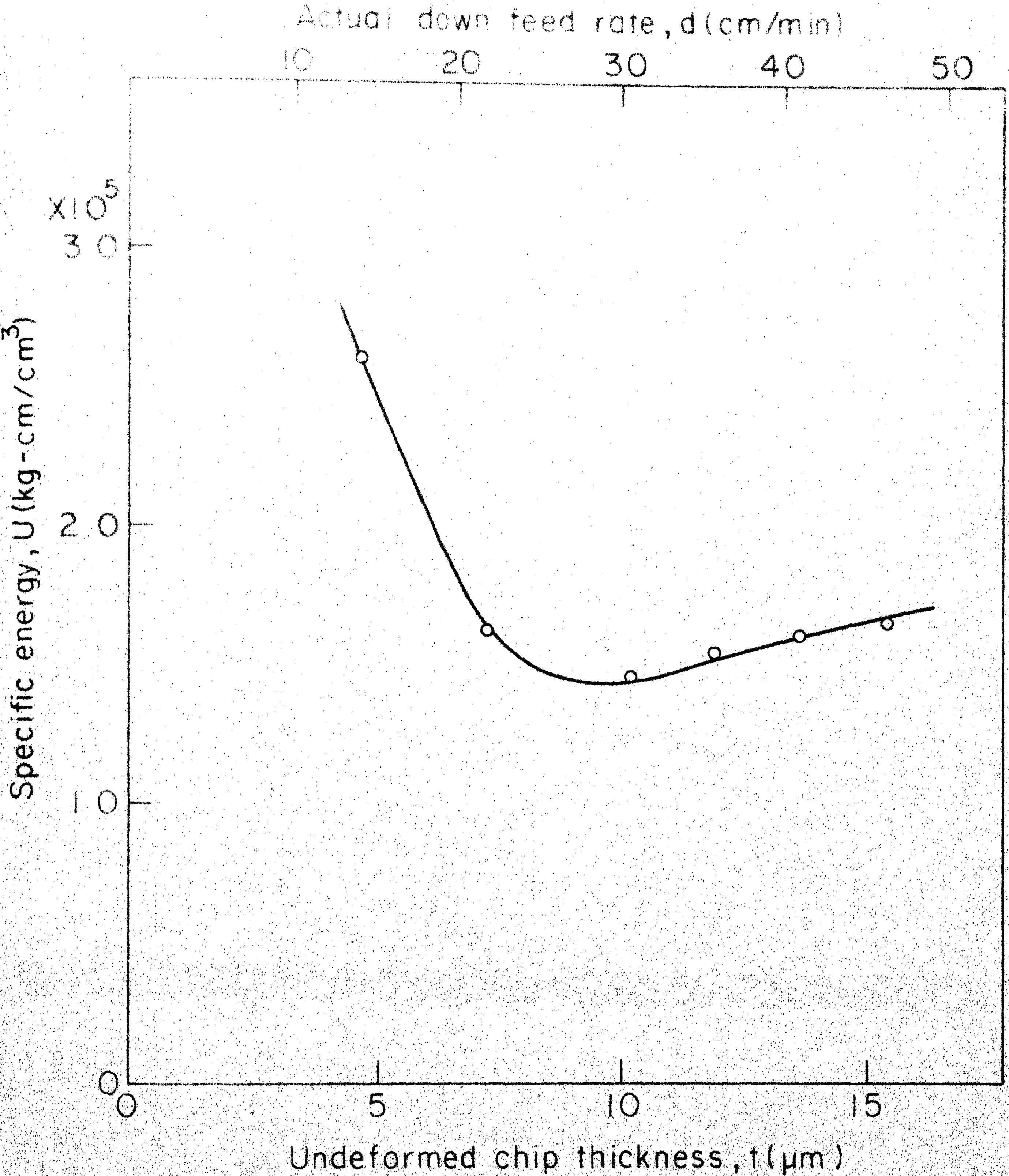

Fig.3.10 Variation of specific energy with undeformed chip thickness

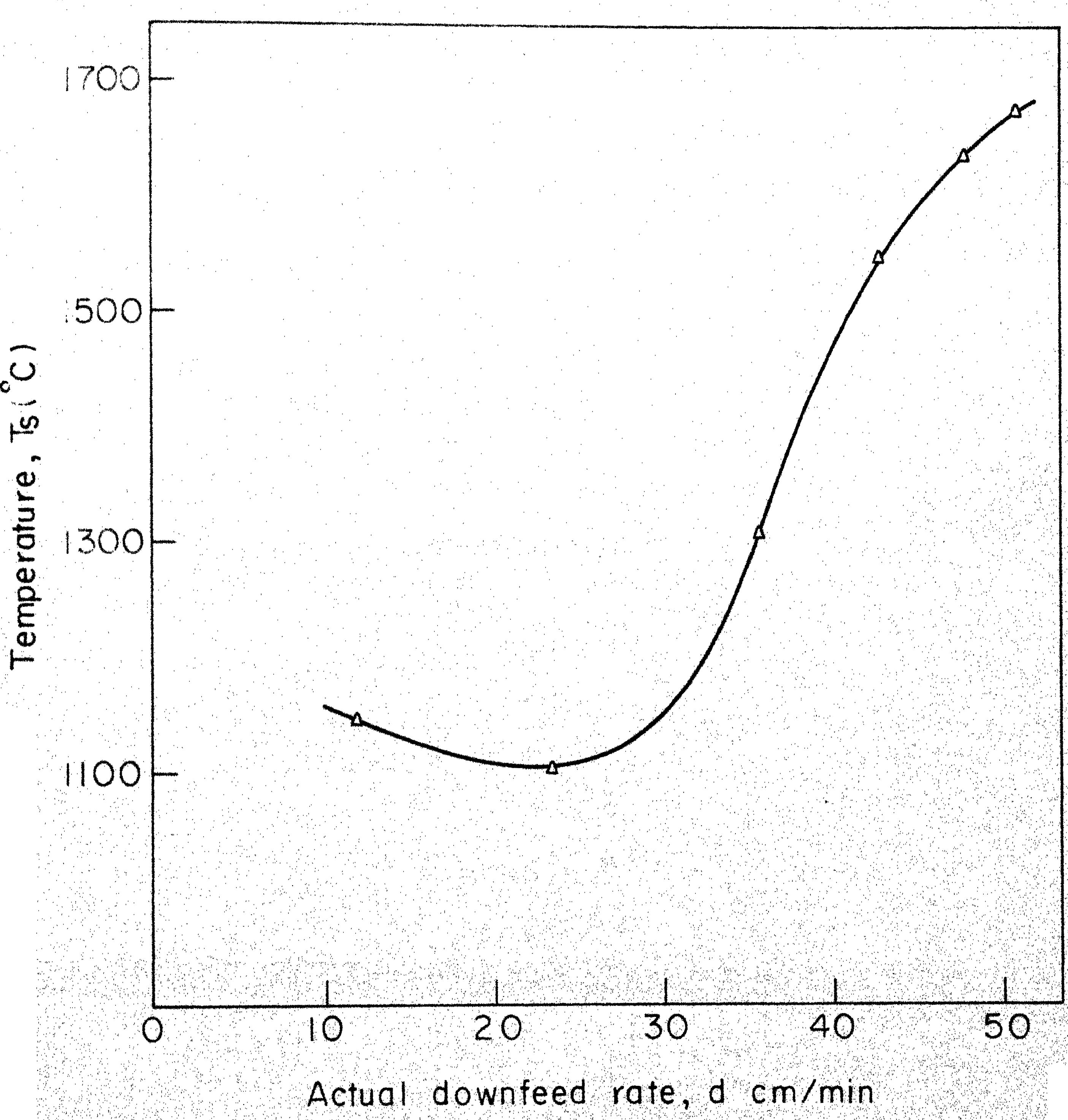

Fig.3.11 Variation of temperature with downfeed rate.

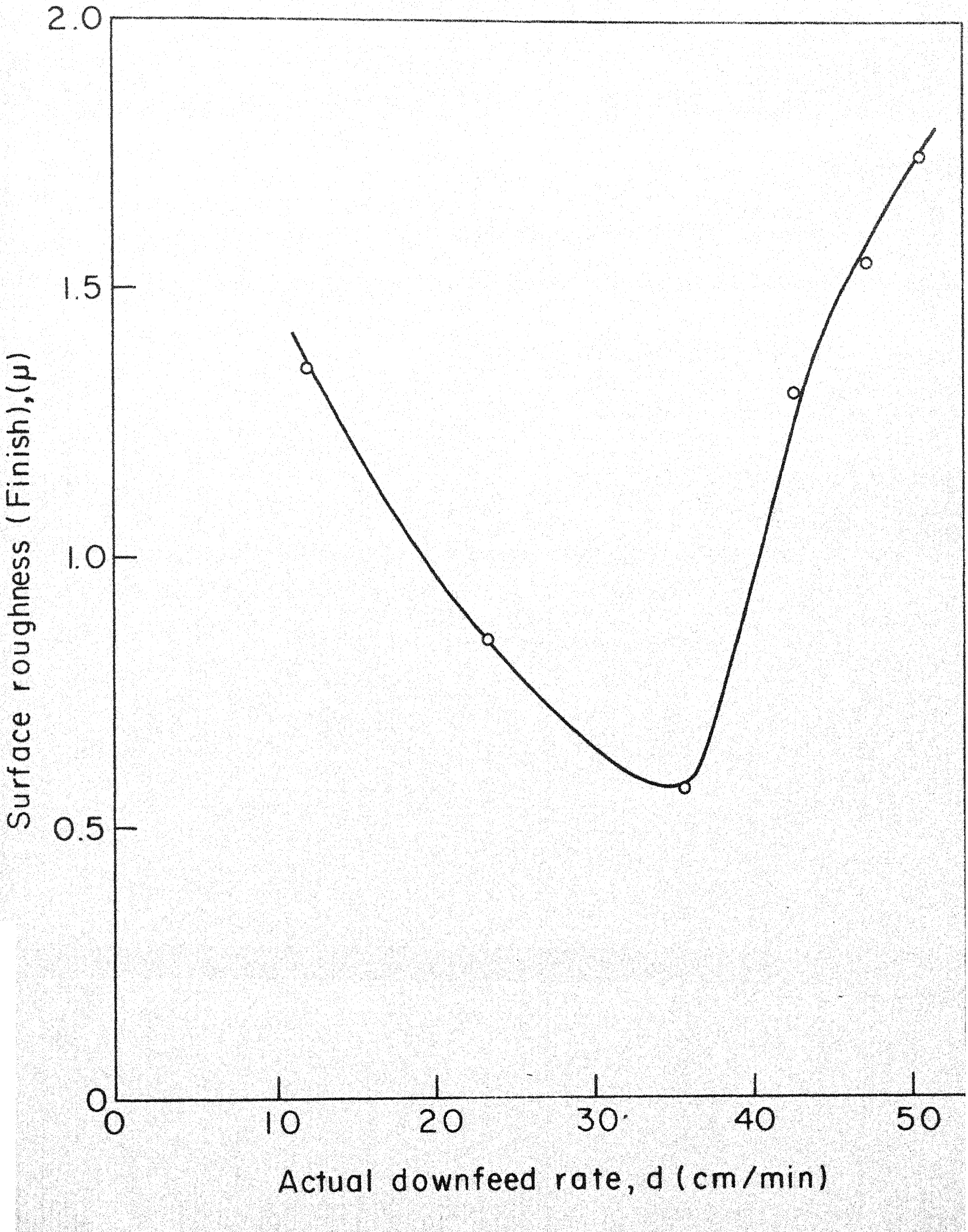

Fig.3.12 Variation of surface roughness (Finish) with downfeed rate

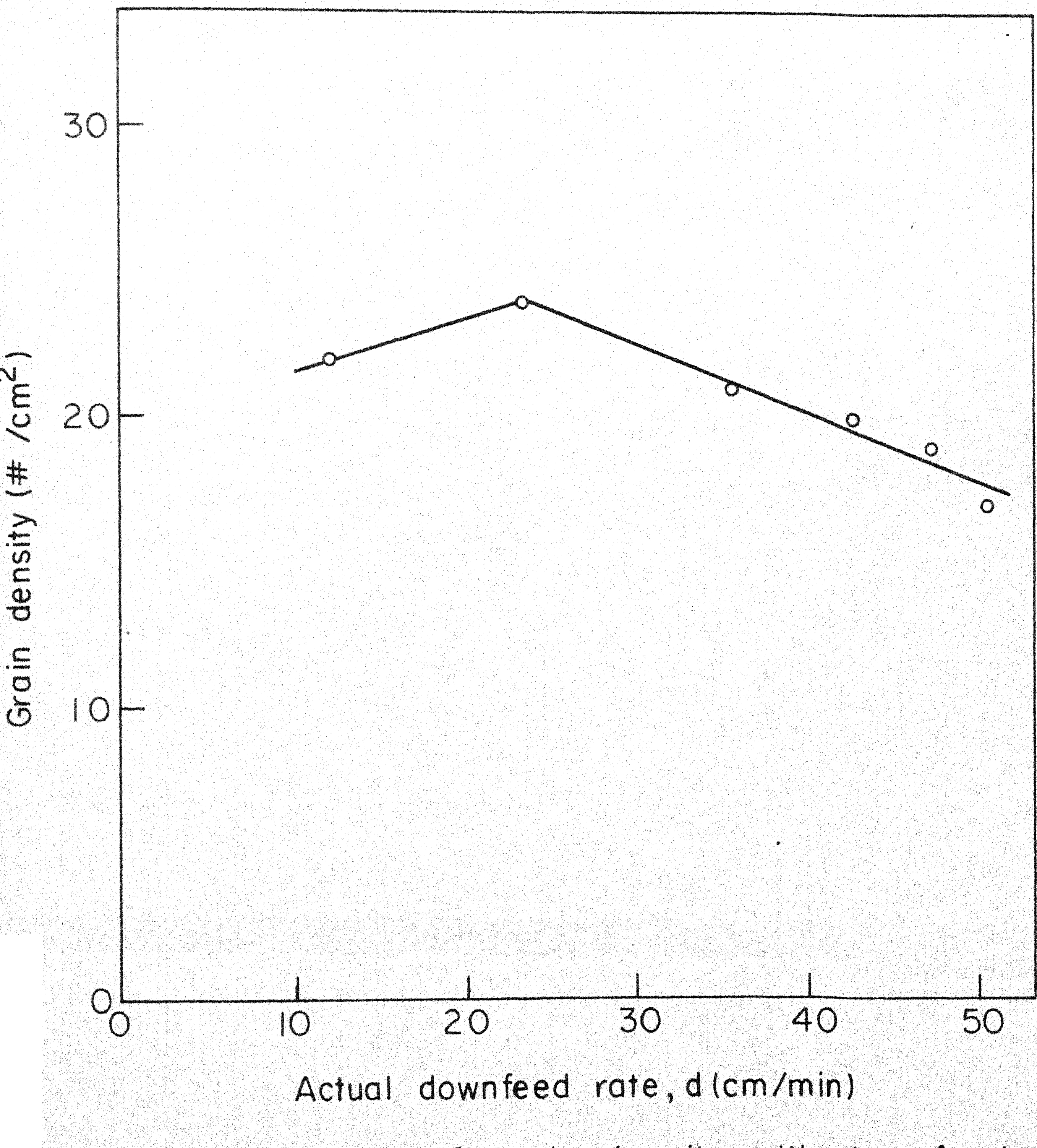

Fig.3.13 Variation of grain density with downfeed rate

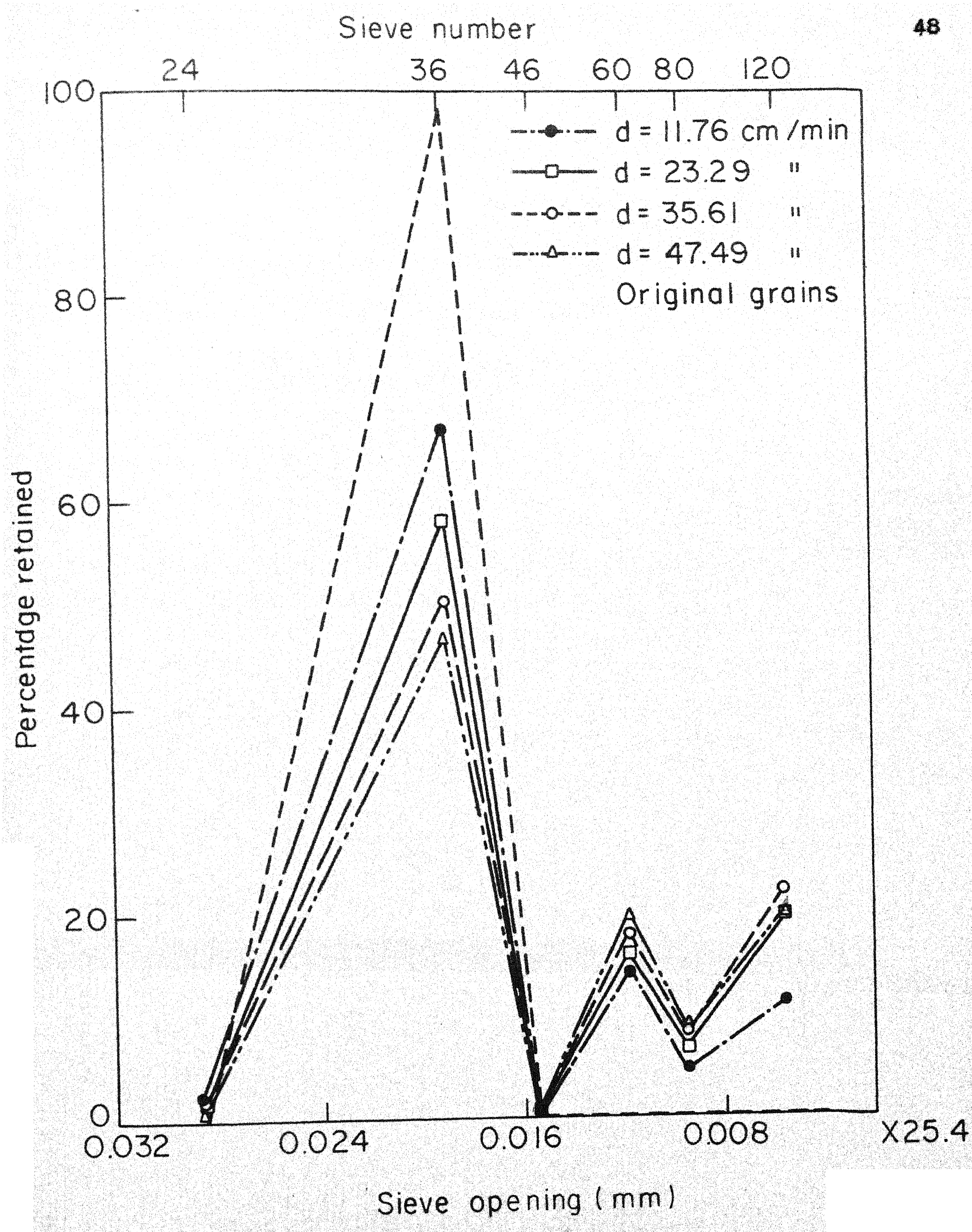

Fig.3.14 Size distribution of wheel wear particles

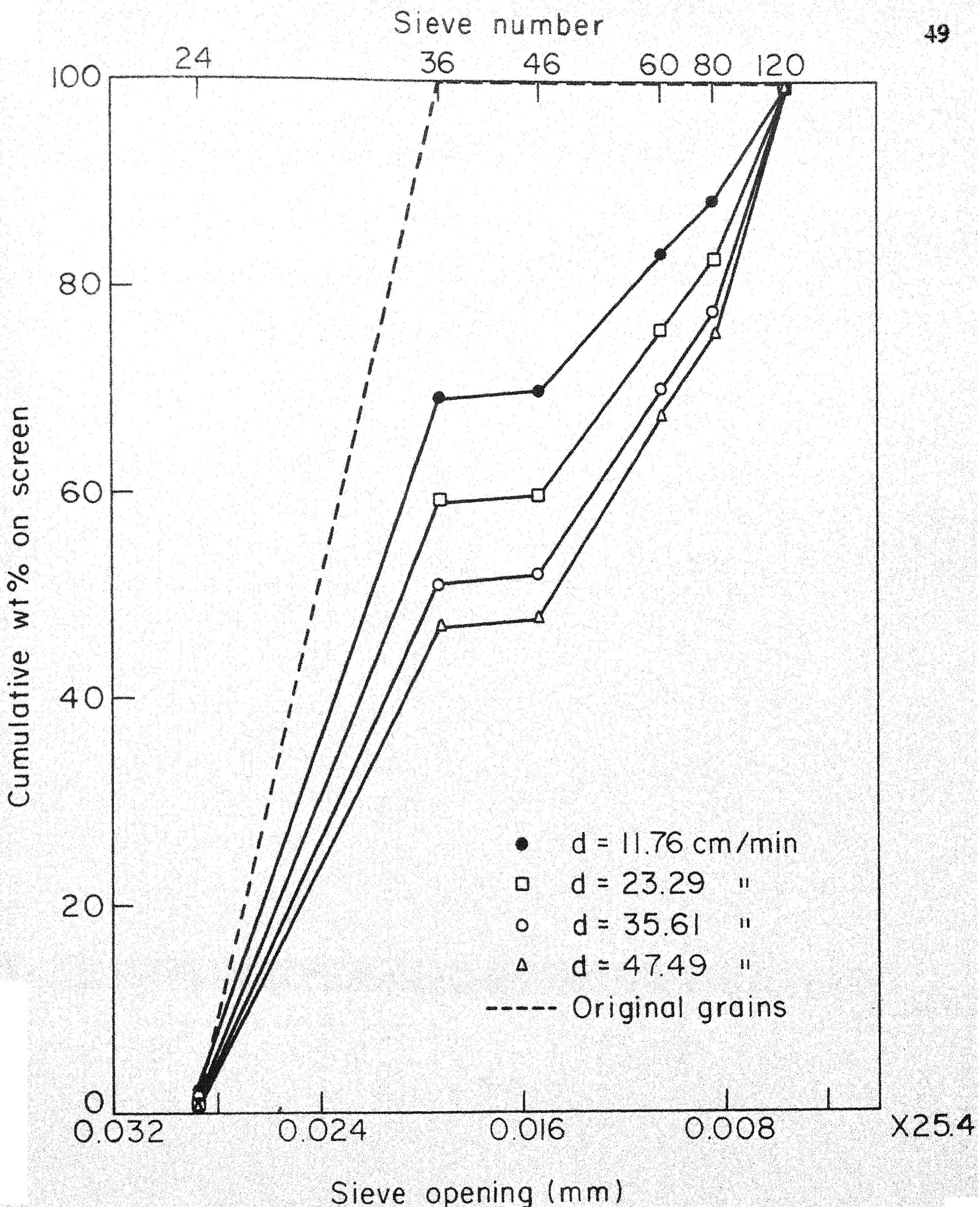

Fig.3.15 Cumulative size distribution of wheel wear particles

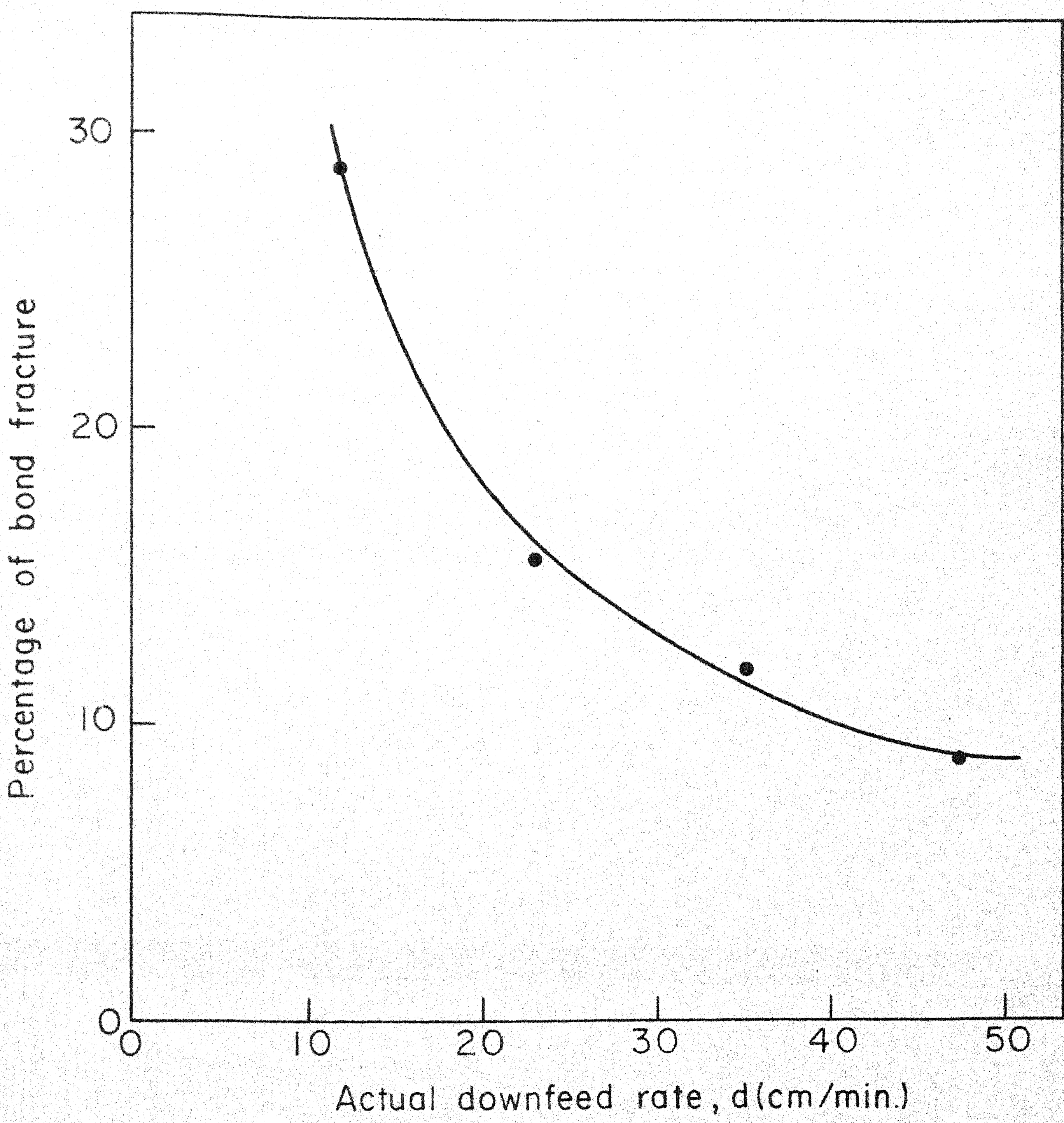

Fig.3.16 Variation of percentage of bond fracture with downfeed rate

CHAPTER - IV

CONCLUSIONS

4.1 Conclusions

The experimental results obtained in this investigation appears to provide a better insight of the abrasive cut-off operation. The important aspect associated with abrasive cut-off wheels appears to be excessive temperature penetration into the wheels at low as well as high downfeed rates. This gives rise to an optimum downfeed relative to wheel wear rate. From specific power consideration it is advisable to operate at down-feed rate slightly lower that the value corresponding to peak grinding ratio. This results in lower specific power and cutting is much freer. It is also clear than, at this optimum downfeed rate the surface finish is better, vibration is less, and number of active grains taking part in cutting is also high. Sieve analysis seems to indicate that in this zone there is right combination of grain and bond post fracture providing most efficient cutting.

4.2 Further work

By performing the tests with different wheel speci-fication on variety of work material, it could be possible to suggest the best wheel and cutting condition for abrasive cutting of a particular material based on the criterion of grinding ratio, cost per cut and production rate.

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APPENDIX 2.1

MACHINE SPECIFICATIONS

		Range values	Units
1.	Size of the cut-off wheel	400 x 3	mm
2.	Cuts solid material upto	60	mm
3.	Cuts pipe O.D. upto	120	mm
4.	Size of rectangular table	500 x 750	mm
5.	Diameter of round table	500	mm
6.	Number of Vee belts	3	
7.	Motor A.C., 440/3/50/2800 rpm	12.5	H.P.
		9.4	K.W.
8.	Wheel spindle speed	2880	r.p.m.
9.	Range of down feed-rate	5 - 60	cm/min
10.	Automatic down feed traverse-length controlled by limit switch	1 - 5	cm
11.	Wheel Bore	25 - 4	mm.